Spatially Targeted Activation of a SMP Based Reconfigurable Skin System

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Overview

Adaptive Structures Team

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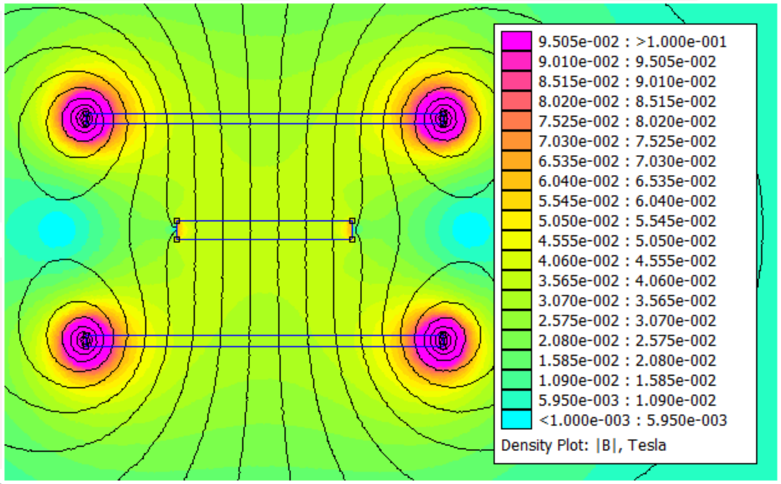
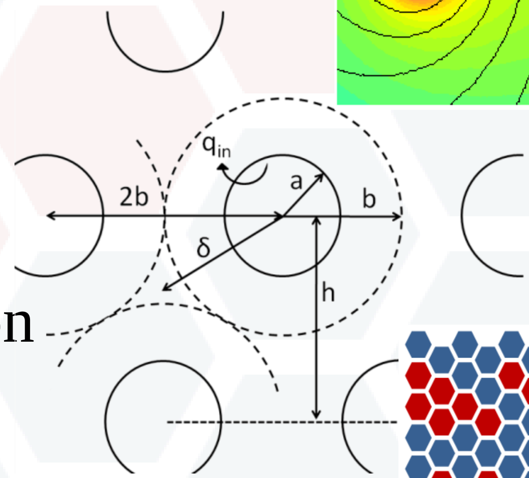
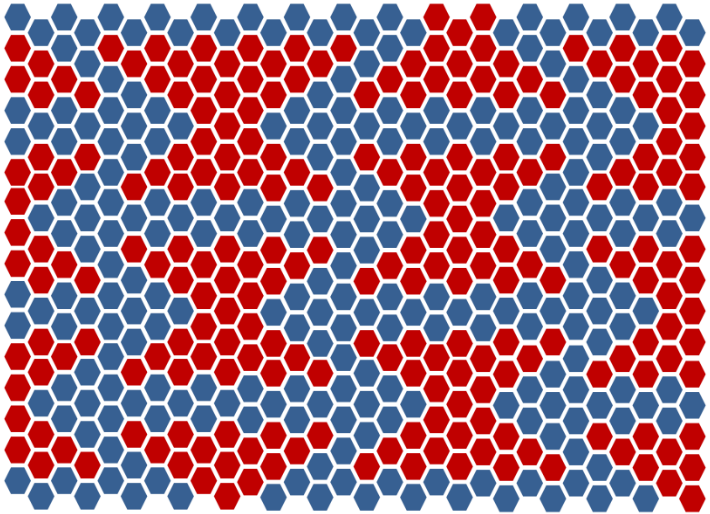
- Future Work
- Summary







RQ Tech Division Consolidation

Adaptive Structures Team

Aerospace Vehicles




High Speed Systems

HIFiRE

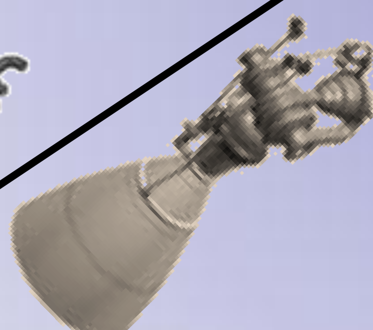


Power and Control

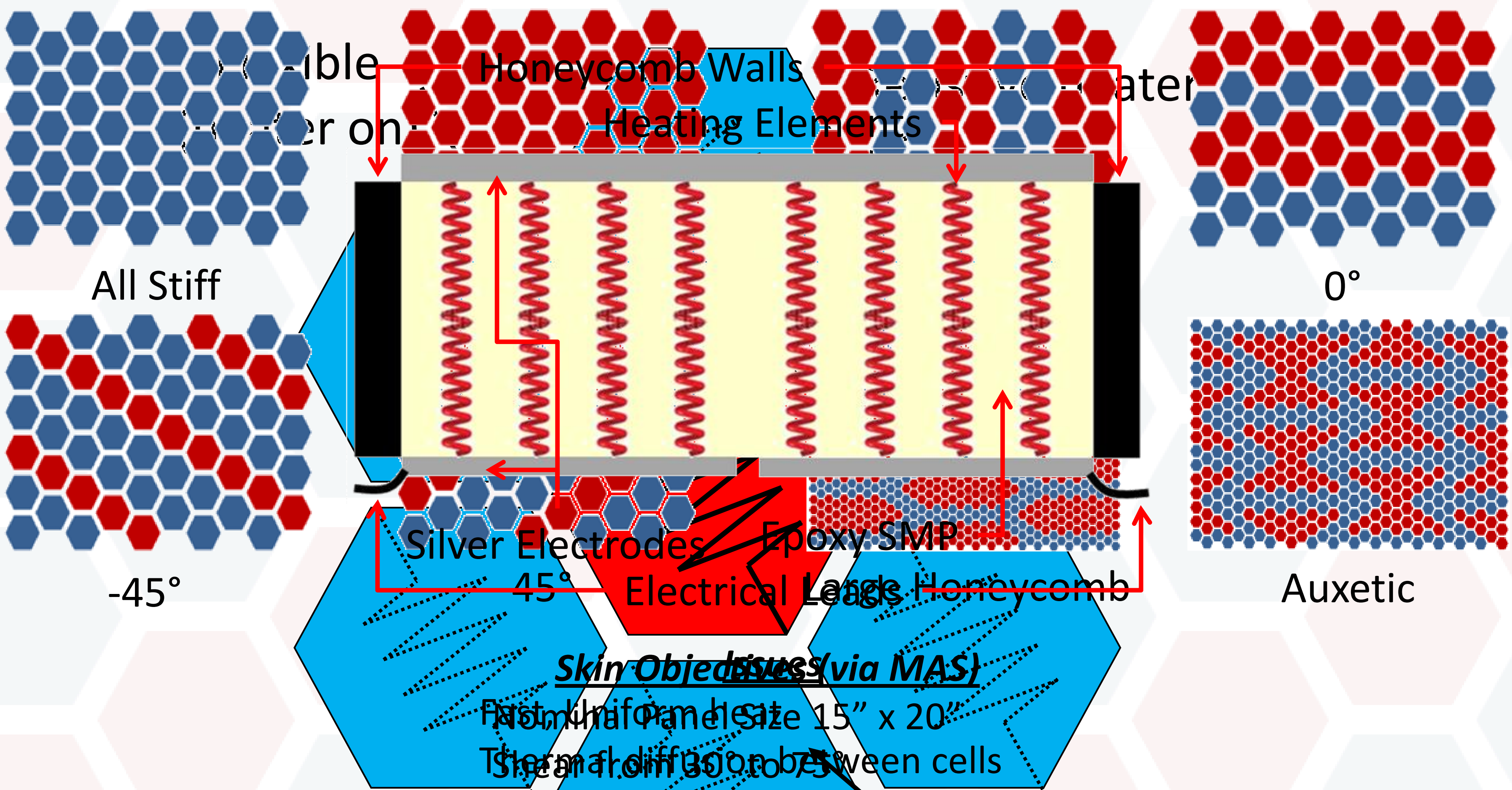


Turbine Engine


Rocket Propulsion




Project Overview



Skin Objectives (via MAS)

- Nominal Panel Size 15" x 20"
- Shear from 30° to 75°
- No Wrinkling of Skin
- Total Skin Weight <0.95 lb/sqft
- Aerodynamic Load 400lb/sqft
- Max Out-of-Plane Deflection 0.1"

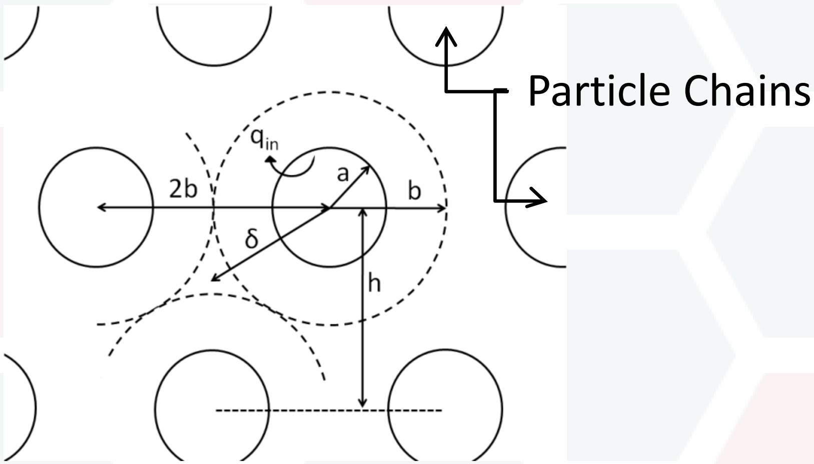
Issues

- Fast, Uniform heat
- Thermal diffusion between cells
- System optimization
- Wiring/Manufacturing
- System weight
- Material characterization/modeling

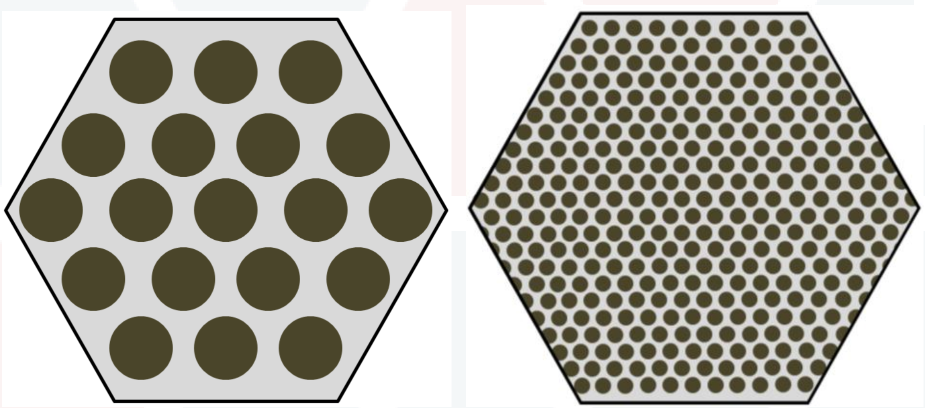
Heating Options

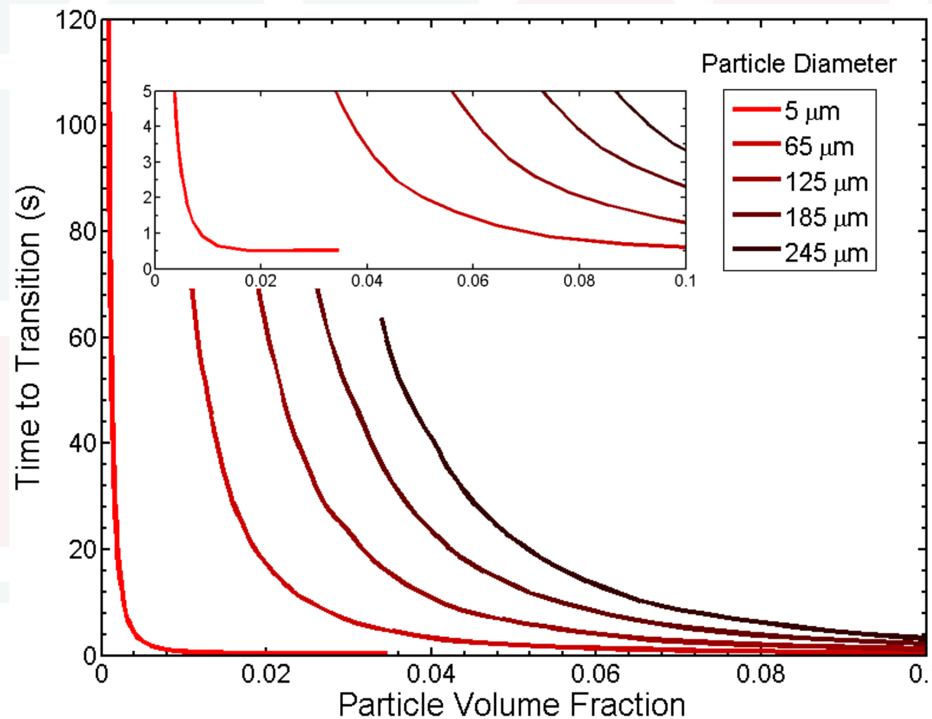
	Strain Capability	Corrosion Resistance	Conductivity	Manufacturability
NiChrome Mesh				
Permalloy80 Particle Chains				
Permalloy80 Random Particles				
NiChrome Wire Coils				
Stainless Steel Wool				
Constantine Wool				
Nickel Random Particles				
Nickel Particle Chains				

Thermal: Modeling



1D Cylindrical Thermal Model

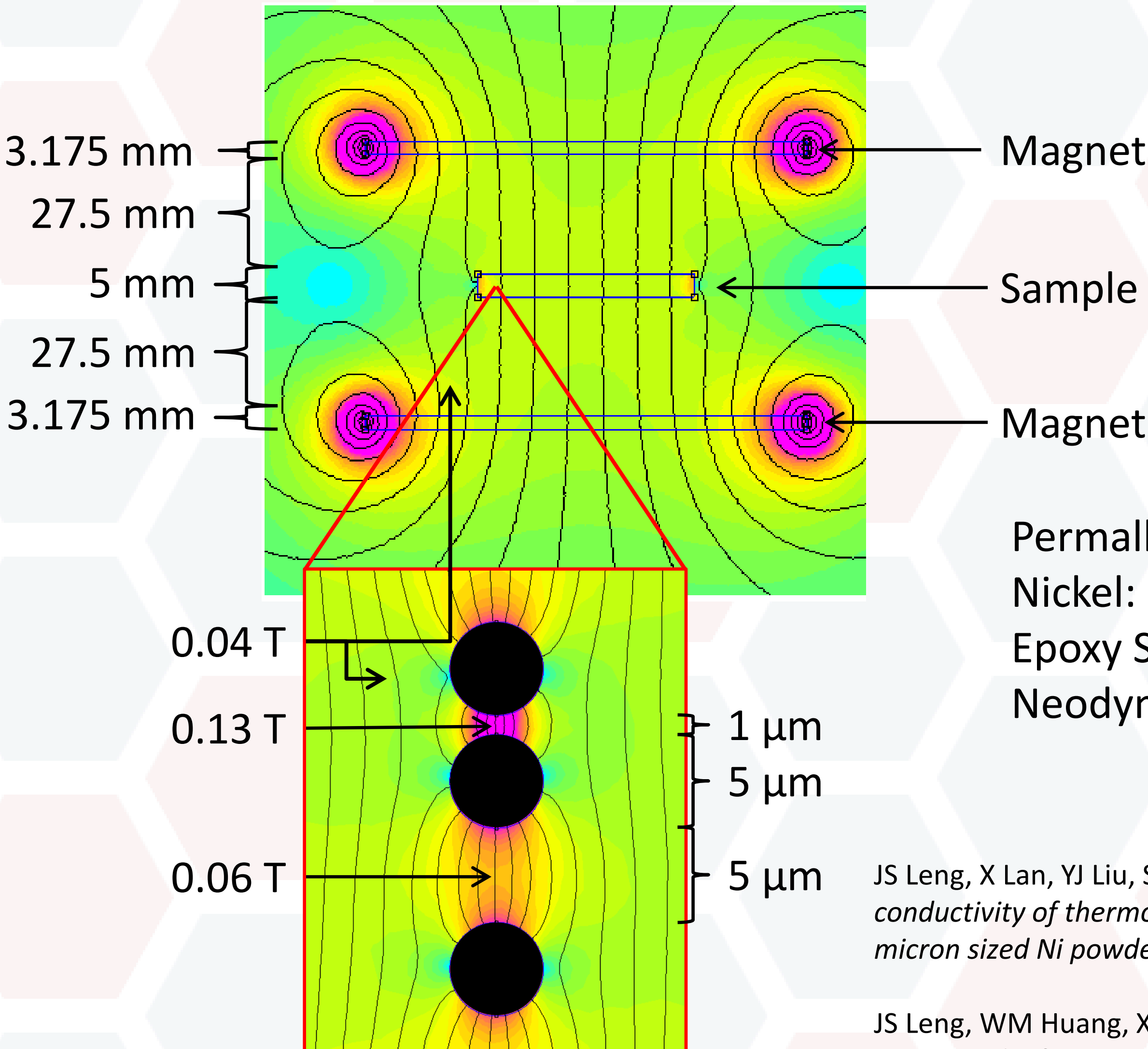




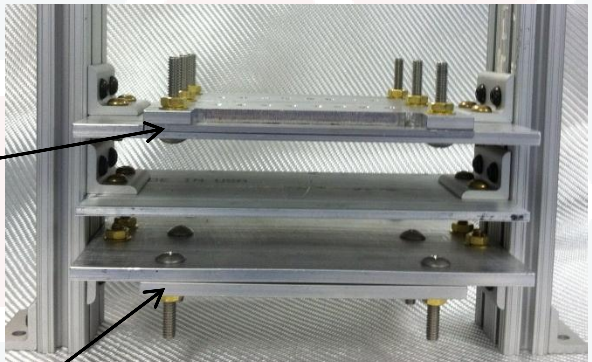
- Surface temp of chain limited to service temp of SMP
- Reduction in power required to prevent damage to SMP
- Builds on previous results of temperature varying thermal properties

Thermal: Magnetic Alignment of Particles

Magnetic Field Lines Between Two Magnets



Magnetic Field Lines b/t Ni Particles

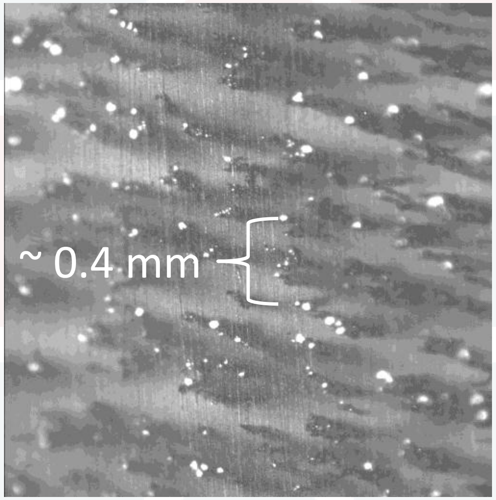


Permalloy 80 (NiMoFe): 37 µm diameter
Nickel: 3-7 µm diameter
Epoxy SMP
Neodymium (NdFeB) N42SH magnets

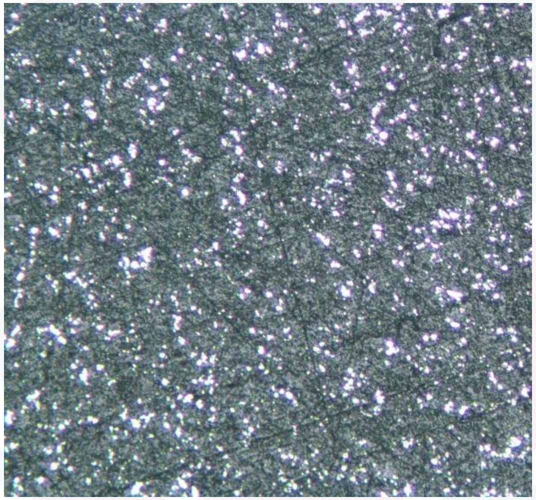
JS Leng, X Lan, YJ Liu, SY Du, WN Huang, N Liu, SJ Phee, Q Yuan, *Electrical conductivity of thermoresponsive shape memory polymer with embedded micron sized Ni powder chains,* Applied Physics Letters, vol. 92, 2008

JS Leng, WM Huang, X Lan, YJ Liu, SY Du, *Significantly reducing electrical resistivity by forming conductive Ni chains in a polyurethane shape memory polymer/carbon black composite,* Applied Physics Letters, vol. 92, 2008

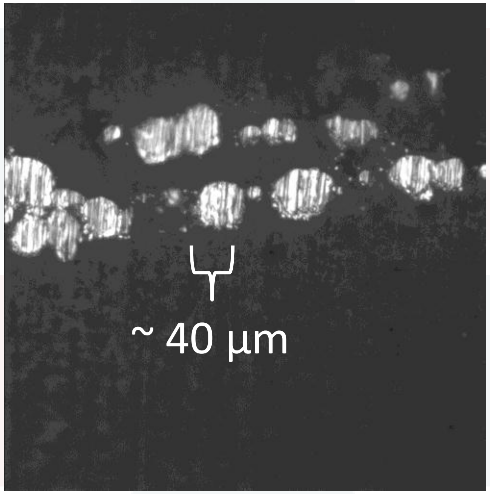
Thermal: Magnetic Alignment of Particles



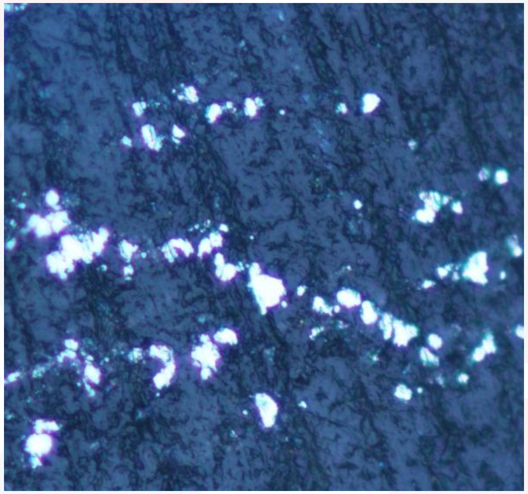
End View of Permalloy80



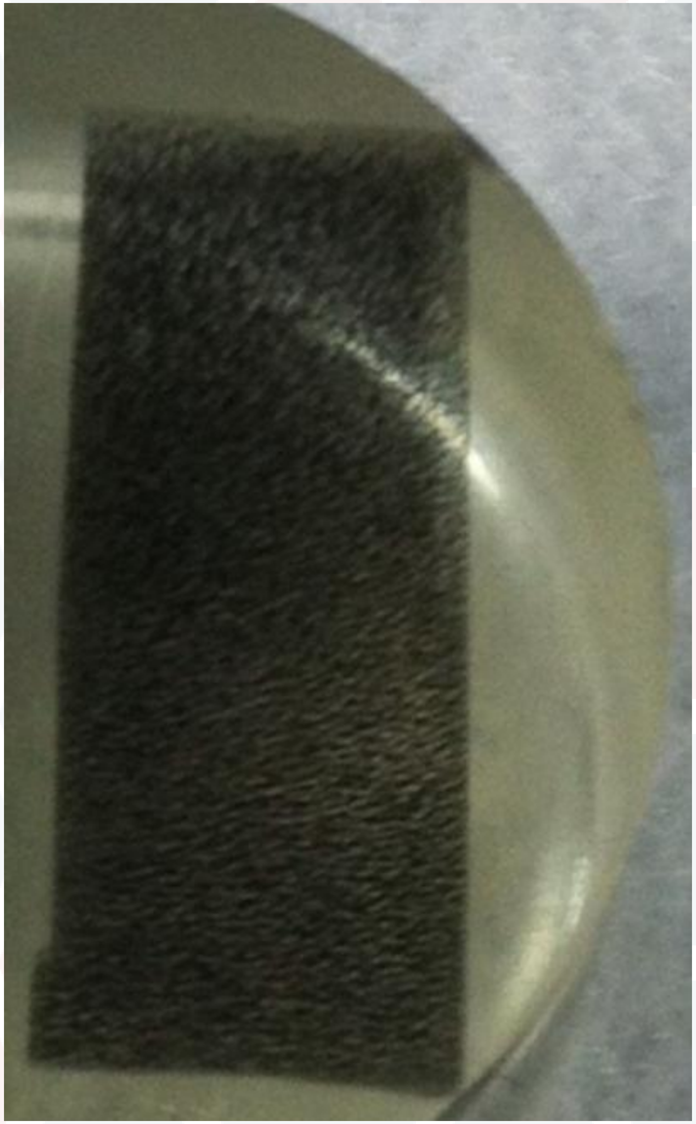
End View of Nickel



Side View Permalloy80



Side View Nickel



End View of Particle Chains

Thermal: Current Results

Material	Diameter	Resistivity (Ω)	Comments
Permalloy80 Particles (random)	~37 µm		Oxidized
Permalloy80 Particles (aligned)	~37 µm		Oxidized
Ni-Cr Coil	0.3 mm	NA	Difficult to Manufacture
Nickel Particles (random)	3-7 µm	80	Viable Option
Stainless Steel Wool	0.08 mm	65	Viable Option
Nickel Particles (aligned)	3-7 µm	**18**	**Viable Option**
Constantine Wire Wool	0.02 mm	11.4	Viable Option
Ni-Cr Mesh	0.25 mm	0.4	Too Rigid

Mechanical: SMP Characterization

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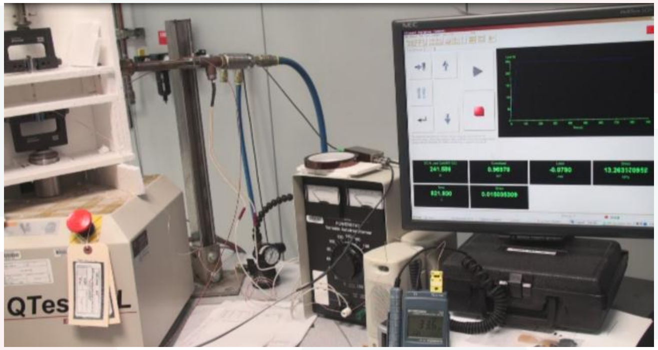
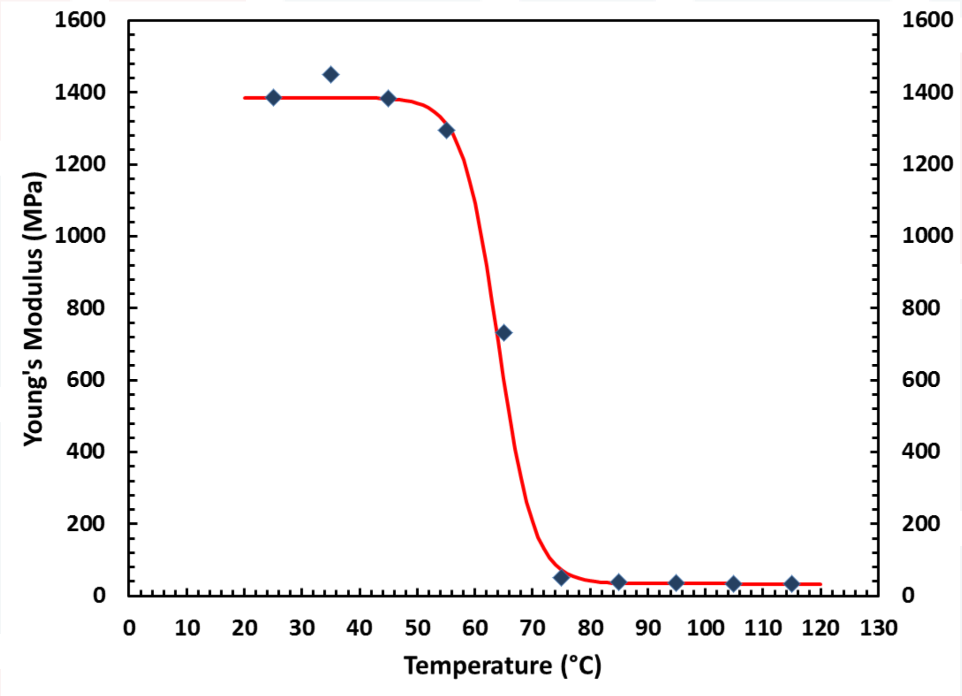
Epoxy SMP Formulation

0.02 mol (7.28g) EPON 826
0.01 mol (2.3g) Jeffamine D230
100°C for 1.5hr, 130°C for 1hr



Epoxy SMP Characterization

Experimental Results	
T_g	65 °C
E (ambient)	1400 MPa
E (115 °C)	32 MPa

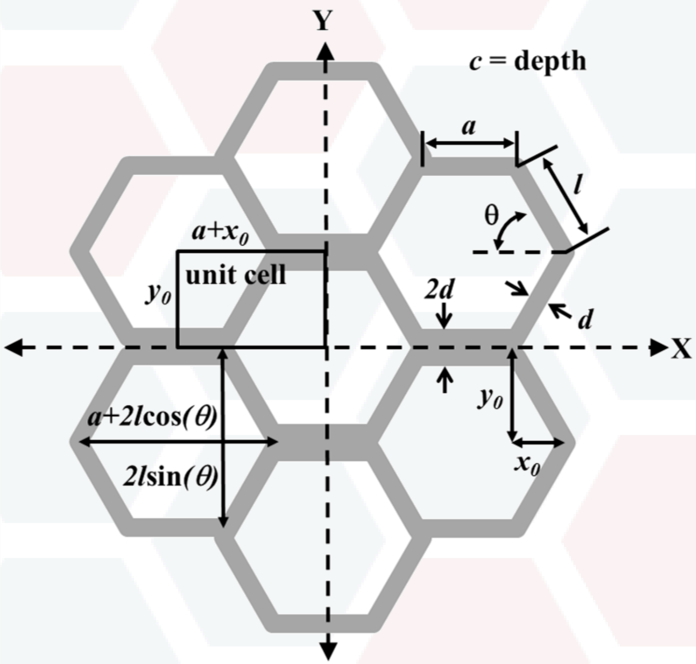


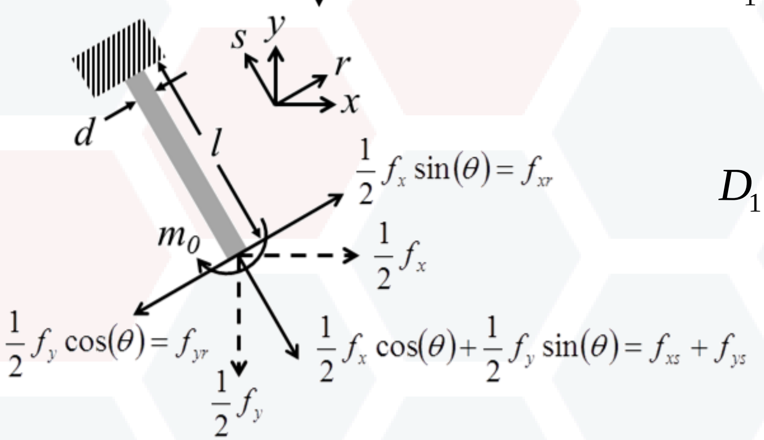
Values consistent over several batches, 0-8 week sample age

T Xie, IA Rousseau, *Facile tailoring of thermal transition temperatures of epoxy shape memory polymers,* Polymer, 2009

Mechanical: System Mechanics Model

Filled Honeycomb Mechanics – In-plane Modulus





Literature Models

$$E_{cx} = B_1 E_h + B_2 E_i$$

$$E_{cy} = D_1 E_h + D_2 E_i$$

B_1, D_1 calculated using strain energy and deformation of honeycomb

B_2, D_2 calculated using strain energy from deformation of infill

Deformation of infill and honeycomb matched to give E_{cx} and E_{cy}

$$B_1 = \frac{12I\left(a+x_0\right)}{cly_0^2\left(y_0+\frac{12I\cos^2(\theta)}{y_0 A}+\frac{6Ia}{y_0 lA}\right)} \qquad B_2 = \frac{(a+x_0)K}{2y_0\beta^2\left(1-\nu_i^2\right)}$$

$$D_1 = \frac{12Iy_0}{c(a+x_0)\left(lx_0^2+\frac{12Iy_0\sin(\theta)}{A}\right)} \qquad D_2 = \frac{y_0 K}{2(a+x_0)\left(1-\nu_i^2\right)}$$

$$K = \beta^3-\gamma\beta^3+\frac{\gamma^2\beta^3}{2}\ln\left(1+\frac{2}{\gamma}\right)+\frac{1}{\beta}+\frac{\gamma}{\beta}+2\nu_i\beta \qquad \beta=\frac{y_0}{x_0} \qquad \gamma=\frac{a}{x_0}$$

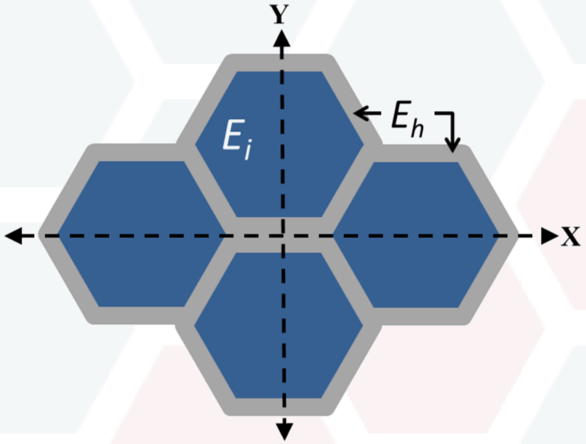
FK Abd El-Sayed, R Jones, IW Burgess, *A theoretical approach to the deformation of honeycomb based composite materials,* Composites,1979

Mechanical: System Mechanics Model

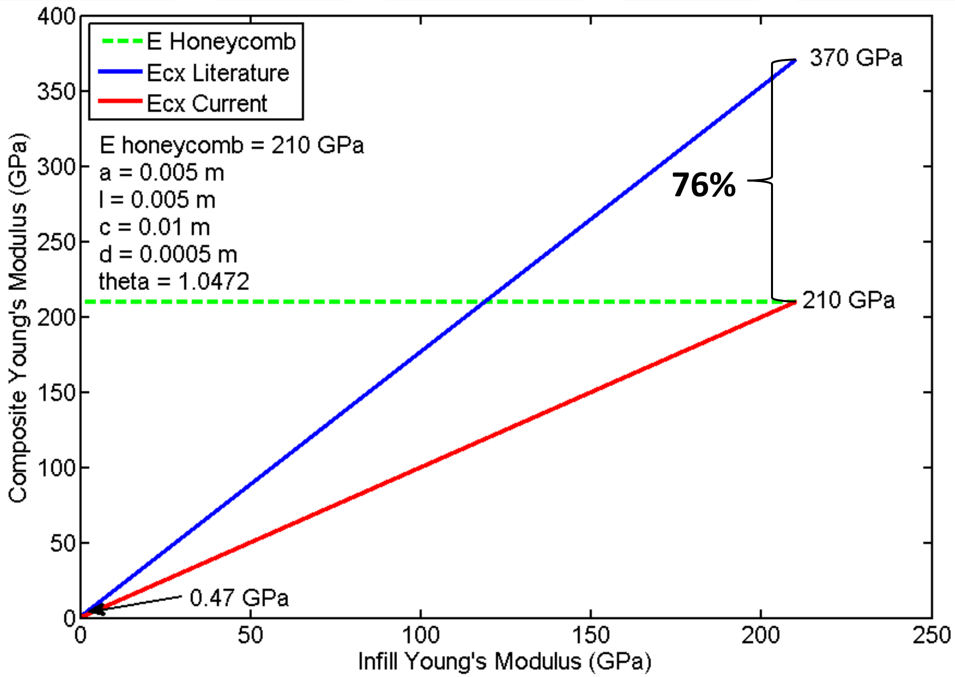
Current Model

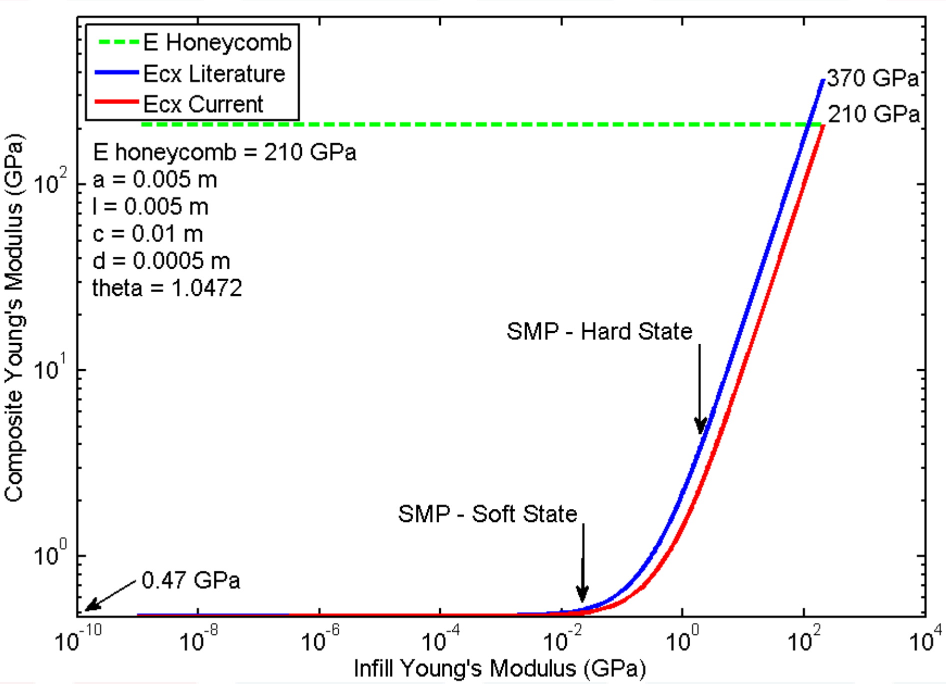
If $E_i = E_h$

Then $E_{cx} = E_{cy} = E_h$



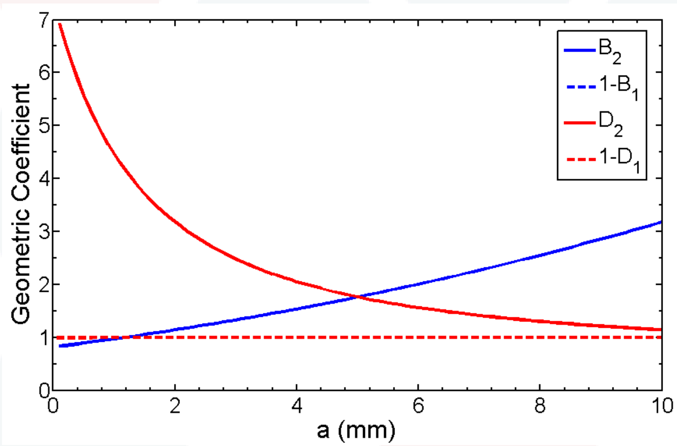
$$E_{cx} = B_1 E_h + (1 - B_1) E_i$$
$$E_{cy} = D_1 E_h + (1 - D_1) E_i$$

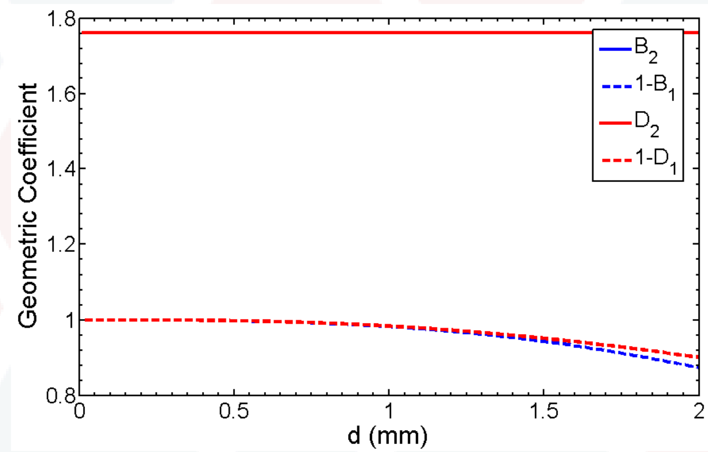


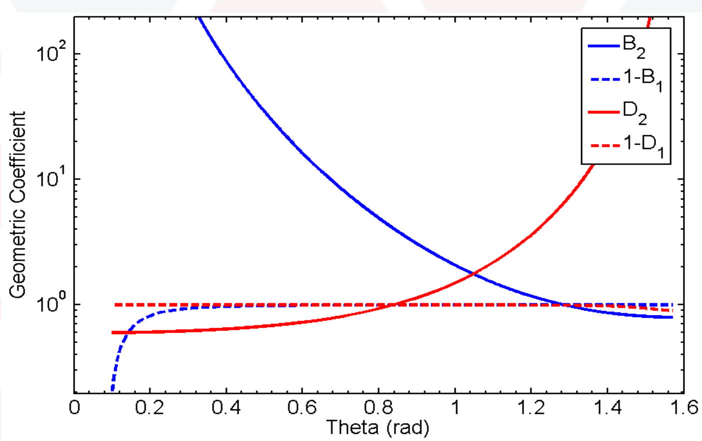


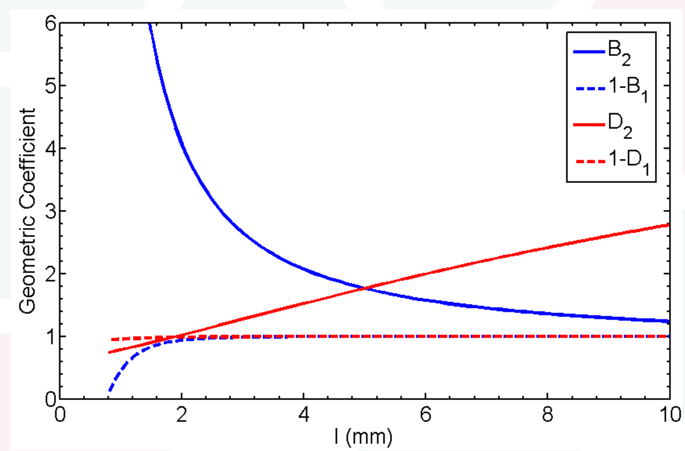
Mechanical: System Mechanics Model

$$E_{cx} = B_1 E_h + (1 - B_1) E_i \qquad E_{cy} = D_1 E_h + (1 - D_1) E_i$$









System Effort: Geometry Optimization

Adaptive Structures Team

Geometry/Environment

Plate: 0.508 x 0.381 m

Load: 19 kN/m^2

Matlab Optimtool Constraints

$\delta = 2.5$ mm

$55° \le \theta \le 75°$

$d \ge 0.2$ mm

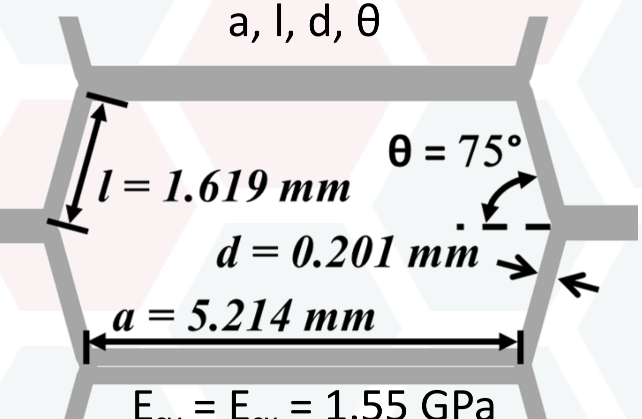
$l, a \le 100$ mm

Objective Function

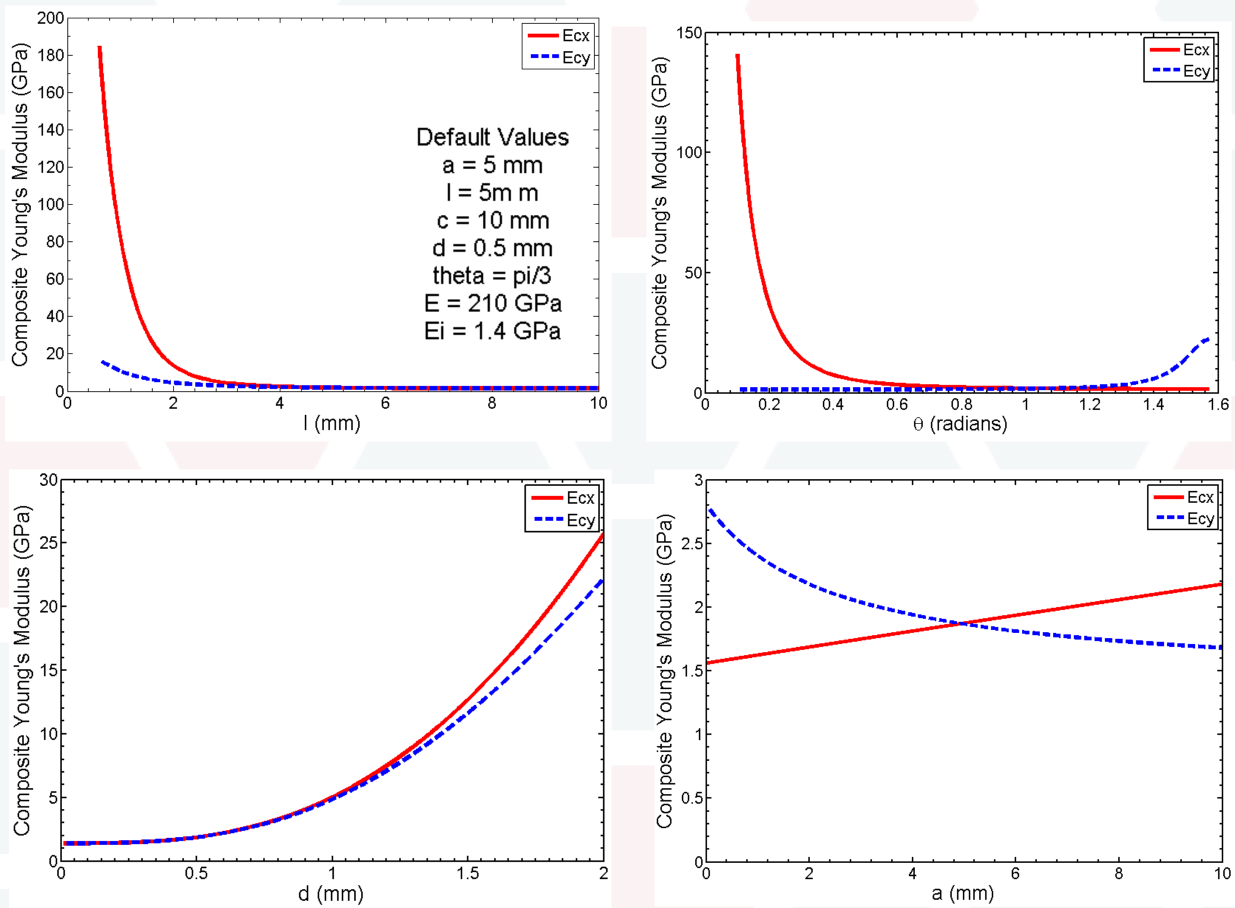
$$Min\left(E_{cx} + E_{cy}\right)$$

Design variables

a, l, d, θ

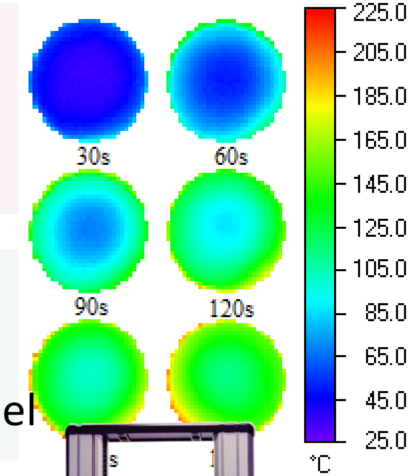


$E_{cy} = E_{cx} = 1.55$ GPa



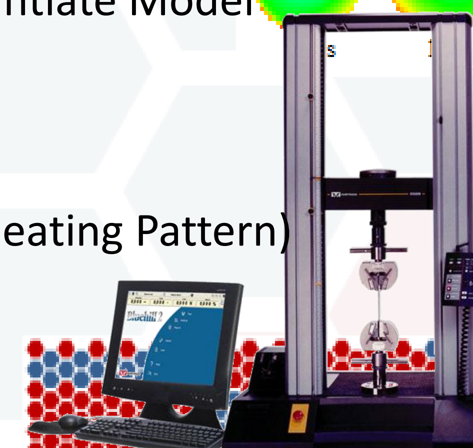
Influence of Design Variables

Future Work

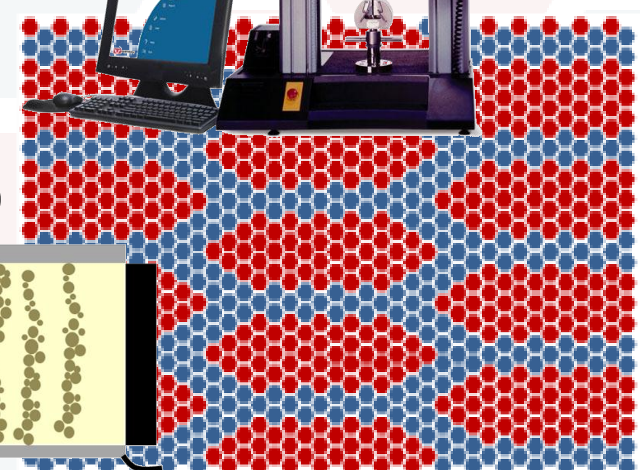


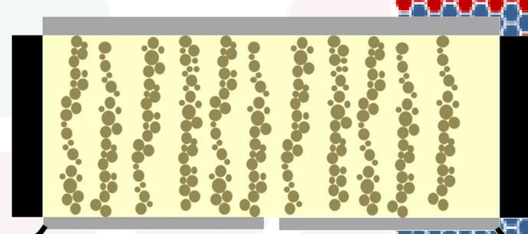
Thermal
- Aligned Nickel Particle Electrical Resistance
- Thermal Imaging (Speed and Uniformity of Heat)

Mechanical
- Static Testing of Various Geometries of Honeycomb to Substantiate Model
- Static Testing of Filled Honeycombs
- Add Shear Modulus and Poisson’s Ratio to Geometry Model
- Continue Refinement of Optimization Model
- FEA Analysis of Filled Honeycomb (Single Cell and Sheet w/ Heating Pattern)

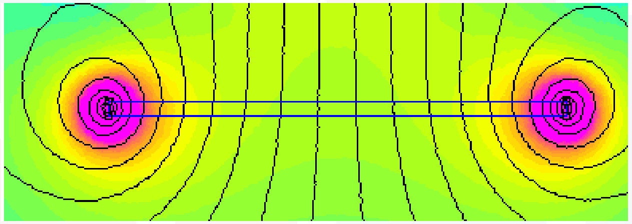


System
- Optimization of Multiple Reconfigurable Shapes
- Fabrication of Entire System (Flexible Electrodes, Wiring, etc.)
- Scaled Pressure Test of Optimized System



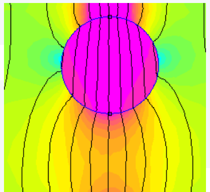


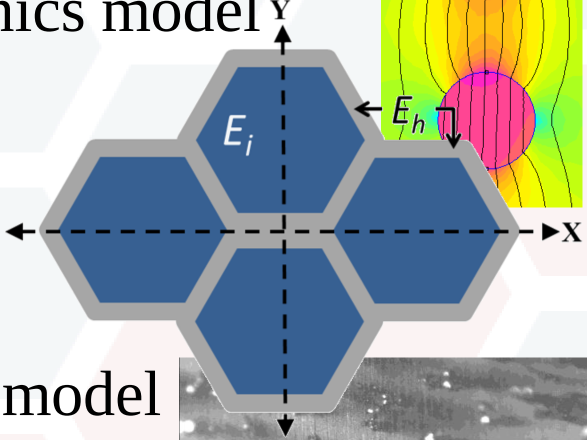
Summary



Major Milestones

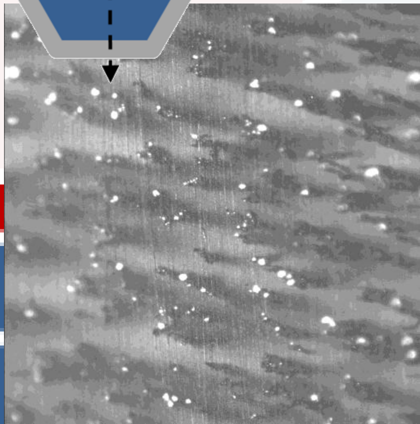
- Characterization of custom SMP
- Thermal model suggests densely packed small wire-like heaters
- Magnetically aligned particle chain heaters promising
- Promising, more accurate composite mechanics model
- Optimization underway of unit cell





Major Challenges

- System integration/wiring/manufacturing
- Composite testing substantiating mechanics model
- Optimization of composite/cell heating pattern



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Thank You

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